CHAPTER 1
INTRODUCTION

Traditional canal-lining materials typically include compacted clay, reinforced or unreinforced concrete, and (more recently) buried geomembranes. However for some jobs, these materials are not always viable for the following reasons: (1) they are not locally available (such as compacted clay), (2) they are too expensive (for example, reinforced concrete), (3) they require large rights-of-way for heavy construction equipment (such as unreinforced concrete), or (4) they require extensive over-excavation and subgrade preparation (such as for buried geomembranes). This study looks at alternative canal-lining materials that are less expensive, easier to construct where access is limited, and compatible with severe rocky subgrades such as the fractured volcanic basalt typically found in the Pacific Northwest.

To date, 34 test sections have been constructed on 11 irrigation districts (five irrigation districts on the Deschutes river in central Oregon, two in Idaho, three in Montana, and one in Oklahoma). The lining materials include combinations of geosynthetics, shotcrete, roller compacted concrete, grout mattresses, soil, elastomeric coatings, and sprayed-in-place foam. The test sections now range in age from 1 to 10 years.

There are five previous reports in this series. The first report "*Deschutes - Construction Report*" (Reclamation Report R-94-06, 1994) documented the construction of the original 18 test sections over severe rocky subgrades on the Arnold and North Unit Irrigation Districts near Bend, Oregon. The Construction Report detailed construction techniques, construction materials, unit construction costs, and ponding tests to determine seepage rates both before and after construction of the test sections. Post-construction seepage rates were 10 to 100 times lower than preconstruction rates.

The second report, "*Deschutes - Year-2 Durability Report*" (Reclamation Report R-94-14, 1994), assessed the condition of the original 18 test sections after about 2 years of service (through April 1994).

The third report, "*Deschutes - Year 5 Durability Report* " (Reclamation Report R-97-01), detailed the construction of 4 additional test sections. That report also assessed the condition of all 22 test sections after up to 5 years of service (through October 1996).

The fourth report, "Deschutes - Year 7 Durability Report" (Reclamation Report R-99-06), details the construction of five new test sections and assesses the condition of all 27 test sections after up to 7½ years of service (through March 1999). The test sections are evaluated for cost, durability, maintenance requirements, and effectiveness in reducing seepage. These factors are combined to calculate life-cycle costs for use in benefit/cost analysis.

The fifth report, "Deschutes - 2000 Supplemental Report" (Reclamation Report R-00-01), details the construction of two test sections constructed in the fall of 1999.

This sixth report details the construction of five new test sections and assesses the performance of all 34 test sections after up to 10 years of service. Tables 1, 2, 3, and 4 show the initial construction costs for all 34 test sections.

These costs should be used for comparison purposes only. Material costs are believed accurate, but should be verified with the geosynthetic manufacturers. These costs are based on a minimum job size of 100,000 to 200,000 square feet (i.e., a minimum of one full truckload of lining materials). Actual construction bids may be somewhat higher, depending on additional items such as mobilization, design costs, additional subgrade preparation, attachment to structures, contingencies, and unlisted items.

In addition to initial construction costs, the 34 test sections are evaluated for durability, maintenance requirements, and effectiveness at reducing seepage. These factors are combined to calculate life cycle costs.

Environmental Assessment of Canal Lining

Seepage from canals may contribute to groundwater and wetlands. The impact on groundwater and wetlands should be assessed prior to canal lining. This assessment may be mandated for projects using federal funding.

Sometimes canal seepage does not return to the river or increase local groundwater. In this case, the canal seepage is lost to beneficial use, and the canal-lining can proceed without further environmental assessment.

More often, canal seepage returns to the river or contributes to local groundwater. Other users may be using this water by diverting from the river or pumping from aquifers. These users may have a legal right to the water leaking from the canal.

Short sections of canal are often lined to mitigate problems associated with canal seepage. These problems often include stability of the canal bank, flooding of nearby houses and basements, and flooding of adjacent farmland removing it from production. In these cases, short sections (typically a few thousand linear feet) of canal are often lined without further environment assessment.

Restoration to Original Condition – Canals that were originally lined with concrete or compacted earth deteriorate over time and experience increased seepage rates. Concrete and compacted earth canal linings have a typical service life of about 50 years. Over time, the concrete cracks, subsides and heaves. Earth linings are gradually removed as the canal is cleaned out each year. A district that over-excavates their canal 1 inch each year, will completely remove a 3-ft compacted clay lining in only 36 years. The water lost to seepage belongs to the canal owner, and it is the owners right to re-line the canal to restore its original condition.

Value of Conserved Water

The B/C analysis uses $50 per acre-ft for the value of the conserved water. This value was selected as a reasonable price for water purchased on the open market. At the low end, farmers typically pay an assessment of $8 to $20 per acre-ft for the water delivered by their irrigation district. Additional water (when available) can usually be purchased for about twice this cost ($15 to $40 per acre-ft). These costs only reflect the costs for building and maintaining the infrastructure and for delivering the water. These costs do reflect the value of the water on the open market. When cities and developers need to purchase water on the open market, they typically pay $100 to $300 per acre-ft, with the higher prices paid in drought years and in areas where water is especially scarce. Based on this range of prices, a value of $50 per acre-ft seemed quite reasonable.

Table 1.— Irrigation Districts that have participated in the Canal Lining Demonstration Project

Irrigation District	Section Identifier	Location (State)	Original Test Sections Installed 1991 & 1992	Test Sections Installed 1994	Test Sections Installed 1994 & 1995	Test Sections Installed 1997	Test Sections Installed 1998, 1999 & 2000	Test Sections Installed 2001	Test Sections Currently being Monitored
Arnold ID	A-1 thru 10	Oregon	10						8
North Unit ID	N-1 thru 9	Oregon	8				1		5
Tumalo ID	T-1 thru 3	Oregon			3				0
Ochoco ID	O-1 thru 5	Oregon					5		4
Juniper Flat Improvement Co.	J-1	Oregon				1			1
Lugert-Altus ID	LA-1	Oklahoma		1					1
Frenchtown ID	F-1	Montana					1		1
Buffalo Rapids ID	BU-1	Montana						1	1
Bitter Root ID	BI-1	Montana						1	1
Lewiston Orchards ID	LO-1	Idaho					1		1
Rick Stone Ranch	TF-1	Idaho					1		1

Note: Ten Irrigation Districts and One Individual Rancher.

Table 2.—Canal Lining Costs - Arnold and North Unit Test Sections

Section No.	Description	Lining Material: Geomembrane $ / ft²	Lining Material: Geotextile $ / ft²	Lining Material: Shotcrete $ / ft²	Lining Material: Other cost $ / ft²	Subgrade Preparation $ /ft²	Installation $ / ft²	Overhead and profit (%)	Total $ / ft²
A-1	4-mil PE Geocomposite with Shotcrete cover								
	Unreinforced Shotcrete	$0.30		$0.87		$0.26	$0.65	17%	$2.43
	Polyfiber reinforced Shotcrete	$0.30		$0.87	$0.06[a]	$0.26	$0.65	17%	$2.50
A-2	30-mil VLDPE textured geomembrane with 16-oz. geotextile cushion and unreinforced Shotcrete cover	$0.25	$0.12	$0.87		$0.26	$0.65	17%	$2.52
A-3	Exposed 80-mil HDPE textured geomembrane	$0.70	$0.12			$0.26	$0.10	17%	$1.38
A-4	Exposed 30-mil PVC with geotextile UV cover cushion	$0.45	$0.07			$0.26	$0.12	17%	$1.05
A-5	Exposed 45-mil Hypalon with 16-oz. geotextile cushion	$0.45	$0.12			$0.26	$0.12	17%	$1.11
A-6	Exposed 36-mil Hypalon with bonded 8-oz. geotextile cushion	$0.50				$0.26	$0.12	17%	$1.03
A-7	40-mil PVC with 3-inch grout-filled mattress	$0.35		$0.65	$0.45	$0.12	$0.60	17%	$2.54
A-8	3-inch Unreinforced grout-filled mattress			$0.65	$0.45	$0.04	$0.50	17%	$1.92
A-9 and A-10	60-mil VLDPE or HDPE with 12-oz. geotextile cushion and 3-inch grout-filled mattress on side slopes only	$0.55	$0.12	$0.21	$0.16	$0.04	$0.45	17%	$1.79
Section No.	Description								
N-1	Spray-applied polyurethane foam with Urethane 500/550 protective coating				$2.41	$0.04	$1.25`	17%	$4.33
N-2	Spray-applied polyurethane foam with Geothane 5020 protective coating				$2.06	$0.04	$1.25	17%	$3.92
N-3	Tietex geotextile with spray-applied Geothane 5020 protective coating		$0.07		$0.90	$0.04	$1.25	17%	$2.64
N-4	Phillips geotextile with spray-applied Geothane 5020 protective coating		$0.07		$0.90	$0.04	$1.25	17%	$2.64
N-5	RCC invert + shotcrete side slopes	Contract Bid Price							$2.00
N-6	Shotcrete - steel-fiber reinforced								
	50 lbs. per cubic yard			$1.08	$0.22	$0.04	$0.65	17%	$2.33
	25 lbs. per cubic yard			$1.08	$0.11	$0.04	$0.65	17%	$2.20
N-7 and N-8	Shotcrete polyfiber reinforced								
	3 lbs. per cubic yard			$1.08	$0.12	$0.04	$0.65	17%	$2.21
	1-1/2 lbs. per cubic yard			$1.08	$0.06	$0.04	$0.65	17%	$2.14
N-9	Unreinforced Shotcrete			$1.08		$0.04	$0.65	17%	$2.07

[a] Cost of Polyfibers

Table 3.—Canal Lining Costs - Tumalo and Ochoco Test Sections

Section No.	Description	Lining Material				Subgrade Preparation $ / ft²	Installation $ / ft²	Overhead and Profit %	Total $ / ft²
		Geomembrane $ / ft²	Geotextile $ / ft²	Shotcrete $ / ft²	Other Cost $ / ft²				
T-1	Liquid Boot over an existing concrete flume	$1.20				$0.15	$0.10	17%	$1.70
T-2	Liquid Boot over a sandblasted steel flume	$1.00				$0.15	$0.10	17%	$2.16
T-3	Liquid Boot over a broomed steel flume	$1.00				$0.10	$0.10	17%	$1.40
O-1a	Covered GCL - Bentomat DN	$0.29				$0.26	$0.15	17%	$0.82
O-1b	Covered GCL - Bentomat CL	$0.33				$0.26	$0.15	17%	$0.87
O-2a	Exposed GCL - Bentomat DN	$0.29				$0.26	$0.10	17%	$0.76
O-2b	Exposed GCL - Bentomat CL	$0.33				$0.26	$0.10	17%	$0.81
O-3a	Exposed 45-mil EPDM PondGard with 8-oz geotextile on side slopes only	$0.30	$0.06			$0.26	$0.10	17%	$0.84
O-3b	Exposed 45-mil EPDM PondGard with 8-oz geotextile on side slopes only and covered invert	$0.30	$0.06			$0.26	$0.12	17%	$0.87
O-4	Exposed 30-mil LLDPE EnviroLiner with 8-oz geotextile on side slopes only	$0.25	$0.06			$0.26	$0.10	17%	$0.78
O-5	Exposed 160-mil Coletanche	$0.93				$0.26	$0.10	17%	$1.51

Table 4.—Canal Lining Costs - Lugert-Altus, Juniper Flat, Frenchtown, Twin Falls, Lewiston, Buffalo Rapids, and Bitter Root Irrigation District Test Sections

Section No.	Description	Lining Material				Subgrade Preparation $ / ft^2	Installation $ / ft^2	Overhead and Profit %	Total $ / ft^2
		Geomembrane $ / ft^2	Geotextile $ / ft^2	Shotcrete $ / ft^2	Other Cost $ / ft^2				
LA-1	Exposed 160-mil Teranap Exposed 120-mil Teranap	$0.95 0.80				$0.12 0.12	$0.10 0.10	17% 17%	$1.53 1.19
J-1	Exposed 160-mil Teranap	$0.95				$0.26	$0.10	17%	$1.53
F-1	Exposed 45-mil PP over a broomed steel flume	$0.40			$0.12[a]	$0.10	$0.15	17%	$0.90
TF-1	Exposed 40-mil Wet-applied Polyurethane Geocomposite over existing concrete	$0.75			$0.15[b]	$0.12	$0.20	17%	$1.43
LO-1	Exposed 45-mil Reinforced Metallocene	$0.32	$0.10		$0.07[a]	$0.26	$0.10	17%	$0.99
BU-1a	Exposed 60-mil GSE White Textured HDPE with 10-oz geotextile cushion	$0.60	$0.12			$0.26	$0.10	17%	$1.26
BU-1b	Exposed 60-mil GSE White Textured HDPE	$0.60				$0.26	$0.10	17%	$1.12
BI-1	Exposed Geocomposite (12-oz geotextile - 30-mil EVA - 16oz geotextile) (8-oz geotextile - 20-mil EVA - 8-oz geotextile)	 $0.53 0.35				 $0.26 0.26	 $0.10 0.10	 17% 17%	 $1.04 0.83

[a] Cost for fabricating panels in the plant
[b] Cost of resin freight